

How clouds create high extremes of surface solar irradiance

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The amount of sunlight a given month or year gets is a commonly observed and discussed statistic of everyday weather. In recent years there have been various new records set. In 2020, north-west Europe experienced its sunniest spring since measurements started (early 1900s), an almost cloud-free period which coincidentally started at the same time as the COVID-related lockdowns. This fits a long-term trend of increasing sunlight, which is only partly explained by cleaner air. This year has again seen exceptionally few clouds in late winter/early spring in parts of Europe.

However, locally and on shorter time scales, you can observe much more solar irradiance if you introduce some clouds - sometimes 60% or more, relative to cloud-free skies. These peaks of so-called "cloud-induced irradiance enhancement" (IE) are found under any broken cloud conditions. The magnitude of the extremes and mechanisms behind them vary greatly with cloud type. Most radiative transfer models do not resolve these observed extremes, primarily due to limiting radiative transport to two streams (up and down) to save computation time.

From observations, we have selected a diverse set of surface solar irradiance patterns under various cloud types and modelled these cloud types in combination with a Monte Carlo ray tracer for accurate 3D radiative transfer. Stratus, altocumulus, and cumulus growing into cumulonimbus are among the studied cloud types. While light scattering in a cloudy atmosphere is complex, we propose that, based on our experiments, just four mechanisms can explain intra-day variability in solar irradiance observations. These four mechanisms are scattering straight downward or in the original direction of light, for thick or thin clouds respectively, with additional effects for vertically structured clouds and surface albedo.